



DIFFERENTIAL GPS: AN AID TO POSITIVE TRAIN CONTROL

Report to the Committees
on Appropriations

Federal Railroad Administration

EXECUTIVE SUMMARY

The report of the Senate Appropriations Committee on the Department of Transportation and Related Agencies Appropriations Bill, 1995, directed the Federal Railroad Administration (FRA) to submit a report regarding the benefits, costs, desirability, feasibility and implications of using current and planned "differential GPS" as a means of promoting the accuracy and utility of positive train control systems. Positive train control systems are technologies having the capability of preventing collisions between trains, avoiding overspeed derailments, and providing other safety and economic benefits.

The Global Positioning System (GPS) data available to civilian users is not sufficiently accurate to meet the safety-related needs of transportation users. The United States Coast Guard is deploying a differential correction service for GPS to enable precision navigation in harbors and inland waterways. Railroads are exploring use of this differential GPS service as a location determination system in emerging communication-based train control systems.

FRA strongly supports development and implementation of communication-based positive train control systems. Such systems have the potential to significantly enhance railroad safety and to provide many additional benefits, including full exploitation of potential line capacity by freight and passenger railroads. Such systems can also lower the cost of train control for new high-speed rail service.

The two primary train location systems that have been actively considered for use in communication-based train control systems are based on differential GPS and transponders. North American railroads are exploring use of both of these location determination systems. At the present time, differential GPS appears to have the advantage of lower initial cost (e.g., all necessary hardware can be placed on the locomotive) and less maintenance (e.g., transponders can be damaged by vandalism or routine track work). The Burlington Northern Railroad and the Union Pacific Railroad have joined together to develop a Positive Train Separation (PTS) Pilot Project on their lines in the States of Washington and Oregon that will employ differential GPS as the primary location determination system.

Differential GPS will soon be available to marine users all along the U.S. coast line and throughout our principal inland waters. With an incremental expenditure of less than \$25 million, sufficient additional transmitters could be placed to provide total coverage of the 48 contiguous States. This highly accurate location determination system could then be used by both rail and highway users, among others. Public deployment of differential GPS will be necessary if this system is to be used by railroads. Private differential services do not offer high reliability, consistent protocols and full land area coverage--

attributes that are essential to interstate rail movements employing interoperable train control systems.

Implementation of communication-based positive train control can prevent accidents and casualties valued at approximately \$35 million per year. However, the initial costs of positive train control systems for U.S. railroads may approach over \$800 million. In addition to equipping trains with location systems, positive train control will require the use of on-board computers, extensive data bases, data radio systems along the principal rail lines, and development of complex on-board and "central office" software. These are costs that private railroads will shoulder to the extent they are convinced that adequate business benefits will result. The Union Pacific/Burlington Northern PTS Pilot Project is persuasive evidence that emerging business needs and maturing technology will converge, leading to the requisite private investments.

Non-safety benefits of positive train control may include better quality service and more efficient equipment utilization through closer tracking of car movements, reduced fuel consumption through pacing of trains, and more effective use of existing infrastructure that effectively increases the capacity of the railroad. Public passenger service providers that operate over freight railroads would also benefit from the capacity and safety benefits of this kind of technology. Over time, intermodal applications of communication-based technology could link highway-based intelligent transportation systems with positive train control systems to yield synergies such as improved safety at highway-rail crossings.

In summary, full deployment of U.S. Coast Guard differential GPS can significantly aid the development of positive train control systems by providing an affordable and competent location determination system that is available to surface and marine transportation throughout the contiguous United States.

Report of the Federal Railroad Administration to the Appropriations Committees:

Use of Differential GPS to Aid Positive Train Control

1.0 Direction

The Report of the Senate Appropriations Committee on the Department of Transportation and Related Agencies Appropriations Bill, 1995 stated as follows:

The Committee supports the current activities within the Department to utilize differential global positioning systems (DGPS) as a means of promoting surface transportation safety and technology. As part of DOT's examination of the potential uses of this technology, the FRA is directed to submit a report to the House and Senate Appropriations Committees by May 1, 1995, on the benefits, costs, desirability, feasibility, and implications of using current and planned DGPS as a means of further promoting the accuracy and utility of positive train control systems.

(Senate Report No. 103-310 at 147.)

This report responds to the Committee's direction.

2.0 Background

Over the past decade, the Federal Railroad Administration (FRA) has supported the railroad industry's effort to develop advanced technology for the control of train movements and the integration and use of information pertinent to train operations. During this effort, FRA has participated in evaluation committees and has collaborated with all parties involved to identify and address obstacles to this development. More recently, FRA promoted deployment of next-generation train control technology through roundtable discussions with industry, labor, suppliers, and other DOT agencies as part of the Federal Railroad Administrator's outreach program. The initial phases of this effort were detailed in FRA's report to the Congress pursuant to section 11 of the Rail Safety Enforcement and Review Act, "*Railroad Communications and Train Control*," ("*Train Control Report*"), dated July 8, 1994.

As noted in the *Train Control Report*, the industry is on the threshold of developing and deploying a family of technologies or systems that can provide for **positive train control**

(PTC). PTC systems are those train control systems that can prevent main line collisions and overspeed derailments, and provide enhanced protection for personnel and equipment working on or adjacent to the track structure. The goal of providing for positive train separation is embodied in one of the "Most Wanted" safety recommendations of the National Transportation Safety Board. Enhanced versions of PTC systems can expand the effective capacity of the railroad and make it more efficient by providing for flexible, moving blocks¹ and precise planning and execution of optimized train operations.

Over the past several decades, the energy efficiency and congestion mitigation potential of railroad transportation has significantly increased the demand for and use of the railroad infrastructure of the United States. Private sector rail service providers have been under increased pressure to address capacity constraints to meet this increased demand.

In 1994, the Burlington Northern and Union Pacific railroads (BN/UP) in a joint project initiated the development of a prototype **Positive Train Separation (PTS)** system to reduce the risk of accidents as well as to provide a foundation for future productivity improvements in the freight railroad industry. The PTS implementation approach is a successor to the freight railroad industry **Advanced Train Control System (ATCS)** project on which major development efforts have been underway for over ten years.

The initial PTS prototype operation is planned for over 800 miles of trackage in the states of Washington and Oregon with testing to begin in 1995 and to be completed in 1996. This project has been endorsed by the Board of Directors of the Association of American Railroads and will serve as a prototype for development of specifications ensuring interoperability among PTC systems nationally. Successful demonstration of PTS is expected to lead to future enhanced PTC applications under which trains would be guided by computer-assisted precision movement plans thereby improving the flow of traffic and optimizing rail plant capacity.

The FRA, as part of the Next Generation High-Speed Rail Program, is sponsoring the development of **High-Speed Positive Train Control (HSPTC)** systems to enable implementation of high-speed rail service in selected corridors on existing track infrastructure, which is often shared with freight railroad carriers. When high speed service is provided on a route, all operating locomotives and control cars must be equipped with train control apparatus. The initial demonstration of HSPTC is targeted at a 44-mile stretch of track in Michigan in 1996. The Michigan project will be coordinated with the UP/BN pilot to ensure interoperability.

Conventional railroad signal systems divide the track into fixed "blocks" between wayside signals. Block lengths are established based upon the maximum stopping distance of long, heavy trains operating at maximum authorized speeds. Operations must be restricted both in the particular block occupied by a train and in at least one adjacent block. Contemporary communication-based signal systems will be capable of defining flexible or moving "blocks" (track segments restricted for exclusive use of the train in question) based on actual train speed, direction of movement, and stopping characteristics. Flexible or moving blocks allow more efficient use of the railroad by increasing the number of trains than can be operated within a given time period.

The basic technologies employed in both of these train control systems can be summarized as follows. Each controlling locomotive will be able to automatically determine its position and will be able to communicate its position and receive instructions automatically by digital radio. The locomotive will be equipped with onboard computer processing capability and a route database. The onboard processor will receive and store instructions with respect to the permitted operating limits and conditions, and the processor will automatically apply the train brakes to safely stop the train if it determines that authorized location permission or speed authorities will be exceeded.

In the past, highly effective automatic train control (ATC) systems have relied upon track circuits for train detection and a limited set of codes sent through the rail to provide cab signal indications. Such systems commonly provide only four indications. These systems are very safe and reliable; but they have limited functions, require fixed blocks (i.e., rigid segmentation of track rather than flexible blocks tailored to particular train movements) and have a high cost to install and maintain. New PTC systems will be communication-based. That is, they will depend upon use of data communication over a variety of paths, including radio, to gather information for integration by microprocessors. The communications platform used by PTC systems may also be available for a variety of other business purposes.

The basic differences between the freight industry PTS approach and the HSPTC approach lie in the degree of control exercised from a central office as compared with distributed field locations. Despite these differences in degree and near-term intent of the systems, for both systems *precise automatic location information is vital to their satisfactory operation*. The PTS project has termed the automatic location element of their system the **Location Determination System (LDS)**, and that acronym will be used in the remainder of this discussion.

One of the principal issues related to PTC is affordability. If systems are highly affordable, they will be widely deployed for both safety and nonsafety business purposes. Wide deployment will mean that collision avoidance and other safety features will be available over a larger portion of the national rail system. Universal equipping of trains with on-board systems will be necessary to realize maximum safety benefits. LDS must be available throughout the national rail system and be compatible with interoperable PTC systems.

3.0 Competing Technologies for Determining Train Location

Presently, there are a limited number of options for selection of a primary LDS. Although information from existing signal systems may be helpful for confirming train location, signal systems are not in place on track constituting about half of the road miles operated. Further, "block occupancy" derived from a signal system will not provide precise location

within a block, speed, or direction of movement. In addition, many existing systems, or portions of them, are "automatic", i.e., operate in the field without central direction or communication--so information from them is not now available at any central location.

Two primary train location systems are currently under development for railroad use: transponders and augmented GPS.

3.1 Transponders

A transponder is a device which receives and retransmits energy. Transponders placed along the track at suitable intervals and at key locations, together with an on-board capability to read digitally encoded information provided by the transponder, is a technically viable option that has been employed in railway signaling internationally.

On the North End of Amtrak's Northeast Corridor (NEC), the existing cab signal/ATC system will be upgraded to provide additional aspects to accommodate higher speed trains as a new part of the traffic mix. An advanced civil speed enforcement system using transponders will be added to that system. Placed between the rails or adjacent to the track, passive transponders will be read by a scanner on-board the locomotive. The transponder will indicate location (including track number), upcoming speed restrictions, the location of the next transponder, and other information as desired. This information can be integrated with information in the on-board computer data base and also transmitted to a central office. Between transponders, odometer readings based on wheel rotation can be used to interpolate train location (with expected error due to wheel slip, etc., added to the safety margin). Because the NEC is electrified (or is under consideration for electrification), because an existing ATC system is in place along the length of the corridor, and because the bulk of the rail equipment operating there is dedicated to that service, the election of transponders for civil speed enforcement and positive stop features on the NEC will not have precedential value for the rest of the United States.

Transponders were also selected as the LDS for the Association of American Railroads/Canadian Railways ATCS specifications, which are now being superseded for U.S. operations by the UP/BN PTS project. ATCS transponders are based on different technology than the European transponders that will be employed on the NEC. Thus, the NEC system will not serve as a valid test of the specific transponder technology that had been under most active consideration for the bulk of the North American freight system. However, the two major Canadian railroads (CN North America and the CP Rail System) continue to experiment with ATCS-compliant transponder systems. There is presently no reason to believe that significant technical problems will be presented.

3.1.1 Transponder Costs

Overall cost for a transponder-based location determination system applied to the U.S. main line rail system could be slightly greater than \$200 million. Of that, perhaps \$180 million might be required for purchase and installation of on-board readers (scanners) for as many as 18,000² locomotives. Approximately \$20 million might be required for purchase of transponders, and additional cost would be incurred in placing them along the track structure. Annual maintenance costs would be incurred that FRA cannot estimate at this time. It should be noted that railroads are concerned that transponders will be subject to damage from production track work, dragging equipment and other causes. Some cost would be incurred to reprogram transponders as circumstances change in the field.

The costs quoted above do not include other necessary components of a PTC system, such as wayside data radios, on-board transceivers and computers, and extensive software and databases. Costs and benefits of PTC systems were estimated in FRA's Train Control Report.

3.2 Global Positioning System (GPS)

Properly "augmented" by a means of correcting small inaccuracies in GPS location data, GPS offers a train location system well suited to operations over the greatest portion of the national rail network. No fixed wayside infrastructure is needed to interface with the on-board equipment. GPS satellite signals are available throughout the United States.

GPS is a space-based radionavigation system which is managed for the Government of the United States by the U.S. Air Force, the system operator. GPS was originally developed as a military force enhancement system and will continue to fill that role. However, GPS also has significant potential to benefit the civil community. In an effort to make GPS service available to the greatest number of users while ensuring that national security interests are protected, two GPS services are provided. The Precise Positioning Service (PPS) provides full system accuracy to U.S. and allied military users. The Standard Positioning Service (SPS) is designed to provide a less accurate positioning than PPS for civil and all other users throughout the world.

System accuracy for the SPS user is maintained at a lower level than the PPS user through the use of Selective Availability (SA). SA is the means by which the U.S. intentionally degrades full system accuracy to an unauthorized user (i.e., SPS user). SA was developed by the U.S. to ensure that an adversary does not use GPS as a military force enhancer against the U.S. and its allies.

Estimates provided are maximums. For instance, it is likely that railroads would not elect to equip all locomotives with on-board systems. Rather, something more than half of the road locomotives (perhaps 8,000 units) would likely be designated as lead units.

SPS is the standard specified level of positioning accuracy that is available, without restrictions, to any user on a continuous worldwide basis. The accuracy of this service is established by both DOD and DOT based on U.S. security interests. This specification states that at a minimum, the SPS user is guaranteed a predictable positioning accuracy of 100 meters (with 95% reliability). Further background and description of GPS and augmentations may be found in "*The Global Positioning System: Management and Operation of a Dual Use System: A Report to the Secretaries of Defense and Transportation*" (Joint DOD/DOT Task Force; December 1993), copies of which are provided for the Committees' files.

Trains and other transportation vehicles will depend upon frequent updates of positioning information. The rate of data transmission for GPS and augmentation systems such as the Coast Guard system described below is adequate to support train control systems. Loss of signal is not expected to be a significant problem. In unusual situations, such as tunnels, locomotive odometer readings can be used to interpolate in the same manner as with transponders.

3.2.1 Differential GPS and the PTC Pilot Projects

As noted above, the civilian or SPS form of GPS has limited accuracy in normal service and is subject to further degradation in times of national emergency. The SA technique is capable of degrading system accuracy by several kilometers or more, as demonstrated in tests conducted by the DOD. These limitations render unaugmented GPS unacceptable as an LDS for train control purposes. However, GPS as augmented with a differential correction system (DGPS) appears to have great promise for performing well as a primary LDS for use in PTC systems.

The first general deployment of DGPS is being undertaken by the United States Coast Guard through local area systems (LADGPS) to provide for harbor and inland waterway navigation. This system will blanket the coasts and major river systems, leaving gaps inland, particularly in the western States. The U.S. Army Corps of Engineers is also planning certain inland radio sites using USCG standards and frequencies.

As noted above, the Burlington Northern Railroad and the Union Pacific Railroad have been jointly developing a pilot project to demonstrate a PTS system (a first-generation communication-based PTC system). The railroads and their suppliers have evaluated their requirements for train location in relation to the Coast Guard's LADGPS system as follows:

- The single most stressing requirement for the location determination system to support the PTS system is the ability to determine which of two tracks a given train is occupying with a very high degree of assurance (an assurance that must be greater than 0.99999 or (0.9₅)). The minimum center-to-center spacing of parallel

tracks is 11.5 feet. Direct GPS *will not* satisfy this requirement. The USCG LADGPS radio tower beacon system, as a first level of augmentation, also *will not* satisfy this requirement. When viewed as a two dimensional area problem, it is unlikely that *any* economically feasible system could achieve this accuracy to the required 0.9₅ probability.

- However, fortunately, the nature of the train location problem is more *one* dimensional, with well defined discrete points (switches) where the potential for diverging paths exists. The USCG LADGPS narrows the location to less than 10 meters (33 feet). The most frequent interval at which successive turnouts can be located (locations at which a train may diverge from its current route over a switch) is 48 feet. Since the train is constrained to be *located on a track*, as opposed to somewhere within an area, this collapses the problem from a two- or three-dimensional problem into a *one*-dimensional problem.
- The *detailed* track geometry data for a specific route are stored on-board the locomotive (needed for calculating the safe braking distance algorithm). Which of two parallel tracks a train is occupying can then be determined by maintaining a continuous record of which direction the train took over each diverging switch point (normal or reversed). There are several heading reference system techniques available to make this determination. Although the final design and choice have not been concluded, they will be sometime between fourth quarter 1995 and mid-1996. DGPS is also proposed as the train location system for the FRA-sponsored HSPTC system.

This analysis supports the utility of DGPS, supplemented by other techniques, to determine train location with a very high degree of confidence.

3.2.2 DGPS Cost Considerations

The cost of equipping 18,000 locomotives with a GPS receiver, a differential beacon receiver, and appropriate antennas could be on the order of \$2,000 per unit or \$36 million total. Annual maintenance cannot be reliably estimated at this time. No fixed infrastructure would be required along the right-of-way.

As discussed below, use of DGPS as the primary location determination system with a PTC system is practicable only if GPS and DGPS services are available with a high degree of reliability throughout the contiguous 48 States.³

Again, the costs quoted above do not include other necessary components of a PTC system, such as wayside data radios, on-board transceivers and computers, and extensive software and databases.

4.0 Public Sector Role in Location Determination: The Future of Augmented GPS

The Department of Transportation and the Department of Defense are working in partnership to identify an appropriate strategy for civilian use of GPS, supported by the National Telecommunications and Information Administration (NTIA), Department of Commerce. Recently the Government agencies prepared "*A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services*" (NTIA Special Publication 94-30; December 1994) ("DOT/NTIA Report"), copies of which are provided with this report for the Committees' files. The DOT/NTIA Report detailed available options for providing location determination systems that can serve the public, including all major forms of transportation, well into the next century. The report made eight recommendations, two of which follow:

- DOT, in coordination and cooperation with the Department of Commerce, should plan, install, operate, and maintain an expanded low frequency/medium frequency beacon system modeled after the USCG's LADGPS system to provide nationwide coverage for land and marine users.
- DOT, in conjunction with other Federal agencies, should coordinate the implementation, operation, and maintenance of all Federally-operated augmented GPS systems to insure optimal use of resources by maximizing commonality of system components.

Since locomotives do not move between points in the contiguous States and Alaska, train control for the Alaska Railroad presents a special case that would warrant separate analysis.

DOT, in conjunction with other agencies, is further reviewing the DOT/NTIA Report prior to deciding what system to implement and recommending how to implement it.

4.1 U.S. Coast Guard (USCG) DGPS

Based upon a review of civilian sector needs, the DOT/NTIA Report recommended consideration of two architectures, both of which would rely upon USCG's LADGPS to provide nationwide coverage for marine and land users.

As noted above, the Coast Guard is already deploying LADGPS for harbor and inland waterway navigation. The 61 radiobeacon transmitters of the LADGPS system will be in place by January 1996 at a cost of \$17.2 million, plus \$5.0 million in maintenance annually. The DOT/NTIA Report estimates that expansion of the LADGPS for universal coverage of the contiguous 48 States would require 20 to 50 additional sites at an initial cost that should not exceed \$25.0 million with annual maintenance that should not exceed \$4.0 million. These costs depend on engineering development that is yet to be completed. The incremental cost of providing complete coverage for land users will be reduced to the extent that the U.S. Army Corps of Engineers establishes USCG-specification LADGPS radiobeacons for its own purposes. As discussed below, the cost might be further reduced through public-private partnerships that provide sites and access to necessary infrastructure.

As discussed above, the BN/UP project and the Michigan HSPTC demonstration will both utilize GPS, corrected by the USCG DGPS system as the primary location determination technology for their PTS pilot project. Initial demonstration of positioning is expected during 1995, and testing and evaluation will be completed by the end of 1996.

4.1.1 Public/Private Partnerships in Deployment of DGPS

Railroads operate one of the most extensive telecommunication networks in the United States, with transceiver base stations placed at over 16,350 locations throughout the Nation. Most of these sites are privately owned by the railroads. This communication infrastructure is necessary to support safe and efficient rail transportation. Railroads pay to acquire, install and maintain this infrastructure and support the work of the Association of American Railroads, which coordinates frequency allocation in the Railroad Radio Service. Railroads also pay licensing and other fees to the Federal Communications Commission.

The costs of deploying and maintaining USCG LADGPS radiobeacons include site acquisition, security and provision of electrical power. Preliminary discussions between the Coast Guard and freight railroads suggests that opportunities may exist for co-location of LADGPS transmitters with railroad radio base stations at reduced cost to the Government over other alternatives. Freight railroads have indicated to FRA that they

would welcome the opportunity to cooperate in filling in the gaps in DGPS which would benefit all of surface transportation.

4.2 FAA Options for Augmentation of GPS

The Federal Aviation Administration (FAA) has also announced a major commitment to use of augmented GPS systems for aviation navigation requirements, including precision approaches. The FAA has developed a Wide Area Augmentation System (WAAS) for aviation use of GPS. This system is not as well suited for train control as is the USCG LADGPS because of terrain masking of the geostationary satellites in many areas where trains must travel.

4.3 Private DGPS Services

The essential technical requirement for the provision of any DGPS service is a one-way communication link which transmits the correction signals to the user from the known location where the correction quantities are generated. Typical DGPS corrections services now being offered utilize data radio, but could easily be sent by wire telephone line or by fiber optic cable. By radio, differential correction signals are transmitted in digital data form using any one of several protocols, provided that the transmitter and receiver are coordinated as to frequency and data protocol.

One radio communication link now occasionally used for DGPS is a "subcarrier" channel of a commercial FM broadcast station. The FM modulation method permits the simultaneous broadcast of program material on one or more subcarrier channels in addition to the main program, at the option of the station licensee. These operations are regulated by the Federal Communications Commission (47 CFR 73.319) on the 100 channels allocated to the FM broadcast service.

Subcarrier transmissions typically cover about the same 45-mile radius from the antenna as the main broadcast channel. Proprietary data and programming coding methods are used to assure that only subscribers have access to the subcarrier program information. Some FM broadcast stations now provide DGPS services via subcarrier channels, using a variety of proprietary data formats. Each such station uses its own proprietary equipment to generate the DGPS correction factors and broadcasts them on its own frequency to its assigned coverage area. Such services can be very useful to localized users, such as land surveyors, who routinely operate in a single metropolitan area and can establish a single commercial relationship with a local DGPS service provider. Such users might want or need to access only one to three DGPS services to assure full reliable coverage of their working territory, even in a very widespread metropolitan area such as Los Angeles.

However, according to the DOT/NTIA report, even maximum implementation of DGPS via FM broadcast subcarrier would likely fail to cover significant portions of the land area

of the western United States, where FM broadcast stations do not now provide full coverage. In addition, the reliability, dependability, and continuity of DGPS service would depend on the equipment and maintenance provided by each local broadcast station licensee, not only for the broadcast transmitter equipment but for the precision differential correction signal generating equipment as well.

For a wide-ranging mobile user, even assuming total national FM subcarrier coverage, a receiver frequency change would certainly be needed and a digital protocol change would not be unlikely each time a user passed from one broadcast station coverage area to another (approximately every 90 miles, or, for instance, every hour for an Amtrak train crossing Kansas at 90 mph.) At each service boundary, the user would either need to know the new frequency, or lose DGPS service until the new source of correction signals could be sought out by testing all of the available FM broadcast frequencies. At best, this kind of administrative infrastructure would be extremely cumbersome.

If PTC systems are to be implemented, railroads will require an effective location determination system which is consistently available across the national rail system. Major gaps in geographic coverage will be unacceptable. Railroads operate in many remote and sometimes sparsely populated areas; in these areas "terrain masking" poses a substantial problem. This terrain masking also inhibits the "line of sight" reception of FM subcarrier broadcast signals in rural areas, as well as those from commercial satellite DGPS providers. Service dependability and reliability must be of the highest order, and any local service failures would result in slowing or stopping rail traffic over widespread areas. For any GPS-based location system, a standard frequency and data format protocol will enormously facilitate implementation of the train control system and will avoid the necessity for multiple DGPS receivers and/or multiple protocols.

Railroads provide service over a national system of some 150,000 road miles. Locomotives now often operate in "pools", and accordingly, operate over wide areas on lines of multiple carriers, often as the controlling lead locomotive. Interoperability of onboard train control equipment will be essential for the railroads to realize the safety benefits of the new positioning technology. It is clear that any augmentation approach that requires onboard receivers to utilize multiple frequencies and to interpret signals encrypted using a variety of proprietary protocols would materially drive up the cost of onboard systems.

Requiring railroads to subscribe to private FM subcarrier services on up to 100 different FM frequencies to cover each broadcast service market would itself add unreasonable continuing expense and administrative burden and thus deter implementation of PTC systems. Since all markets presently served by subcarrier FM services are local, there is no basis to estimate potential costs of such service to railroads (which would require high-reliability continuous service to thousands of mobile units at any given time.)

Use of FM subcarrier transmission of DGPS correction signals is eminently suitable for local users. However, this transmission method is unsuitable to operate mobile units on a nationwide basis.

5.0 PTC Costs and Benefits

As noted above, our national investment in LADGPS has already been substantially committed. Implementation of the U.S. Coast Guard LADGPS will support safe and efficient marine navigation in our harbors and inland waterways for decades to come. A further initial investment of less than \$25 million can fill in the gaps in coverage across the contiguous United States. This LDS will then be available to aid the safety and efficiency of interstate commerce by highway and rail, as well.

If LADGPS is completed as a LDS available to surface transportation, railroads could make extensive use of DGPS at an initial cost for the LDS alone of less than \$40 million. In the Train Control Report, FRA has estimated that collision and overspeed railroad accidents cost the Nation approximately \$35 million *per year*. Were LADGPS a complete train control system, the costs of completing the system would be recovered in less than two years based on this application alone, even accounting for reasonable maintenance expense.

Of course, an LDS would be only one element of a complete communication-based train control system. In order to test their PTS technology in the Pacific Northwest, for instance, the Burlington Northern and Union Pacific are putting in place a data radio system all along their rights-of-way, equipping locomotives with on-board computers and custom software, developing data bases that describe in detail the entire railroad territory, developing office software than can communicate with existing computer-aided dispatching systems, and working intensively with other railroads and FRA to ensure that the completed system will have the capability to be interoperable with other train control systems developed in the future.

The Association of American Railroads has estimated that development and deployment of communication-based PTC throughout the industry could cost over \$800 million, before expenses for maintenance. Obviously, these costs cannot be justified by avoidance of accidents and casualties alone. However, railroads are exploring the potential for other benefits, which may include--

- Higher quality service, through continuous tracking of car movements.
- Reduced fuel consumption, through better pacing of trains (avoiding the need to take away momentum through braking and restore it through use of diesel power).

- More efficient use of existing physical plant, increasing effective capacity while avoiding further outlays to build additional tracks or sidings.

These potential benefits may be valued in the hundreds of millions of dollars annually. However, the extent to which these "business benefits" of PTC will be realized is a matter of continuing study and dispute within the railroad industry. Railroads such as Union Pacific and Burlington Northern obviously believe that the investment may prove worthwhile. Other railroads may determine that they can realize many of these same benefits using less expensive technology (e.g., cellular digital phones in lieu of data radio) or may not face the same capacity constraints that may motivate higher-density carriers.

Ultimately, privately owned freight railroads will make decisions regarding investment in PTC based on their own financial bottom lines. These decisions will powerfully affect the safety and cost of their operations.

Over time, the safety and affordability of publicly-funded intercity and commuter rail service will depend upon the freight railroad's commitment to PTC investments. If freight railroads deploy the communication infrastructure to support PTC and equip their locomotives with interoperable PTC, the incremental cost of this safety system for passenger carriers will be quite low. Extensive use of PTC by freight railroads will keep the cost of marginal line capacity lower, as well, benefitting passenger railroads and their customers.

Benefits of a nationwide surface LDS would not be limited to freight and passenger railroads. Precise positioning creates the potential for highway-side benefits, as well, including systems that could provide enhanced warning for collision avoidance at highway-rail crossings. As in the case of PTC, additional expenditures would be required to realize these benefits. Those expenditures would have to be justified based on their merits and after appropriate research and demonstration.

In sum, the costs of completing the LADGPS system are quite low in relation to the potential benefits that a completed system could facilitate. Because LADGPS will cost significantly less in public and private investment than the principal LDS alternative (transponders), its implementation could provide the critical impetus for PTC, if private business decisions are in doubt. Further, LADGPS offers the opportunity to provide a common positioning method for highway and rail, with the possibility for significant intermodal benefits.

6.0 Conclusions

Based on available information, USCG DGPS offers the greatest likelihood of meeting location determination requirements for PTC systems. Since low frequency/medium frequency beacons offer the best area coverage in the immediate future, a DGPS system such as the Coast Guard's LADGPS will provide the railroad infrastructure with a seamless navigation and positioning system in both urban and rural areas of the country. Other benefits of this architecture include the ease of system compatibility with highway and waterway systems under development or deployment. Intelligent Transportation Systems currently under consideration may include the USCG LADGPS system in their navigational and positioning system architecture.

Early, full deployment of USCG LADGPS as recommended in the DOT/NTIA report could provide a seamless and reliable location determination capability that can support and hasten the deployment of positive train control systems, while helping to achieve synergies between PTC and other Intelligent Transportation Systems. Public/private partnerships could hold down the incremental cost of deployment. Positioning services that are available to all users can serve as integrating element for all facets of a National Transportation System.